Phase I Ground Water Compliance Action Plan for the Tuba City, Arizona, UMTRA Site

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1.0 Introduction

This Phase I Ground Water Compliance Action Plan (GCAP) for the Tuba City, Arizona, Uranium Mill Tailings Remedial Action (UMTRA) Project site describes the first phase, Phase I, of ground-water remediation activities that will take place at the Tuba City site. Phase I is expected to last approximately 3 years. The second phase, Phase II, will include expansion of remediation capacity and monitoring to assure that the project aquifer restoration standards are met. A Phase II GCAP will be prepared to document the additional remediation activities completed.

Remediation of surface contamination was achieved when the disposal cell at the Tuba City site was completed. The Remedial Action Plan (DOE 1989) documents the design and compliance aspects of the disposal cell. A summary of the site history and extent of ground-water contamination are provided in this GCAP as background information. Detailed information about the site and nature and extent of contamination is in the Tuba City Site Observational Work Plan (DOE 1998).

The Phase I GCAP provides a brief background of the site, describes the compliance strategy, the selected remediation method, and components of the Phase I remediation. Details of the Phase I remediation components are found in the design drawings, specifications, and operational plans that are part of the project record. Section 2.0, "Site Information," summarizes contamination in the ground water, describes the ground-water flow system and how it interacts with surface water in the area, and discusses the extent of contamination in the aquifer. Section 3.0, "Compliance Plan," discusses the regulatory drivers and documents how the compliance strategy selection process defined in the Programmatic Environmental Impact Statement (PEIS) (DOE 1996) was used to select the compliance strategy at the Tuba City site. Section 4.0, "Selected Remedial Action," describes the remediation method that will be used to comply with the standards in 40 CFR 192, discusses the implementation plan for the remediation, and discusses limitations of the remediation method.

2.0 Site Information

2.1 Location

The Tuba City UMTRA site is located in Coconino County, Arizona, just south of
U.S. Highway 160, in Section 20, Township 32 North, Range 12 East. The site is within the
Navajo Nation and close to the Hopi Reservation, approximately 5 miles east of Tuba City and
85 miles northeast of Flagstaff (Figure 2–1). It is approximately 6,000 feet (ft) northwest of and
300 to 400 ft in elevation above Moenkopi Wash, an intermittent stream that drains to the
southwest into the Little Colorado River. Figure 2–2 shows features of the site such as the
disposal cell, drainage channels, and site boundaries.

The site lies at an elevation of approximately 5,100 ft above sea level on a terrace that slopes
gently to the southwest. The terrace surface is a thin veneer of unconsolidated dune sand and
gravels that overlie the Navajo aquifer (N-aquifer). Land near the site is used only for occasional
grazing; adjacent land is used for dry and irrigated farming and for residences. Water from
Moenkopi Wash is used for stock watering and agricultural diversions by the Navajos and Hopis
near the site. The limited and highly variable supply of surface water makes ground water an
important resource in the area.

2.2 History

The uranium mill at the Tuba City site operated from 1956 to 1966. The mill processed
approximately 800,000 tons of ore during the 10-year period. Between 1956 and 1962, the mill
processed an average of 300 tons of ore per day using a sulfuric acid leach. The plant was
reconfigured in 1962 to use sodium carbonate in an alkaline process, and from 1963 to 1966 an
average of 200 tons of ore per day were processed. All tailings from mill processing were placed
as a slurry in evaporation ponds at the site; these ponds covered an area of 33.5 acres.

The U.S. Department of Energy (DOE) began surface remedial action at the Tuba City site in
1988. The uranium mill tailings and associated materials were moved and stabilized in an
engineered disposal cell on site. Surrounding windblown contaminated soils also were placed in
the disposal cell. The Tuba City site was licensed by the U.S. Nuclear Regulatory Commission in
1997. The license deferred ground water cleanup to the UMTRA Ground Water Project.

2.3 Ground-Water Characteristics

This section summarizes the ground-water characteristics near the Tuba City site. The Tuba City
Site Observational Work Plan (DOE 1998) presents a more complete and detailed discussion of
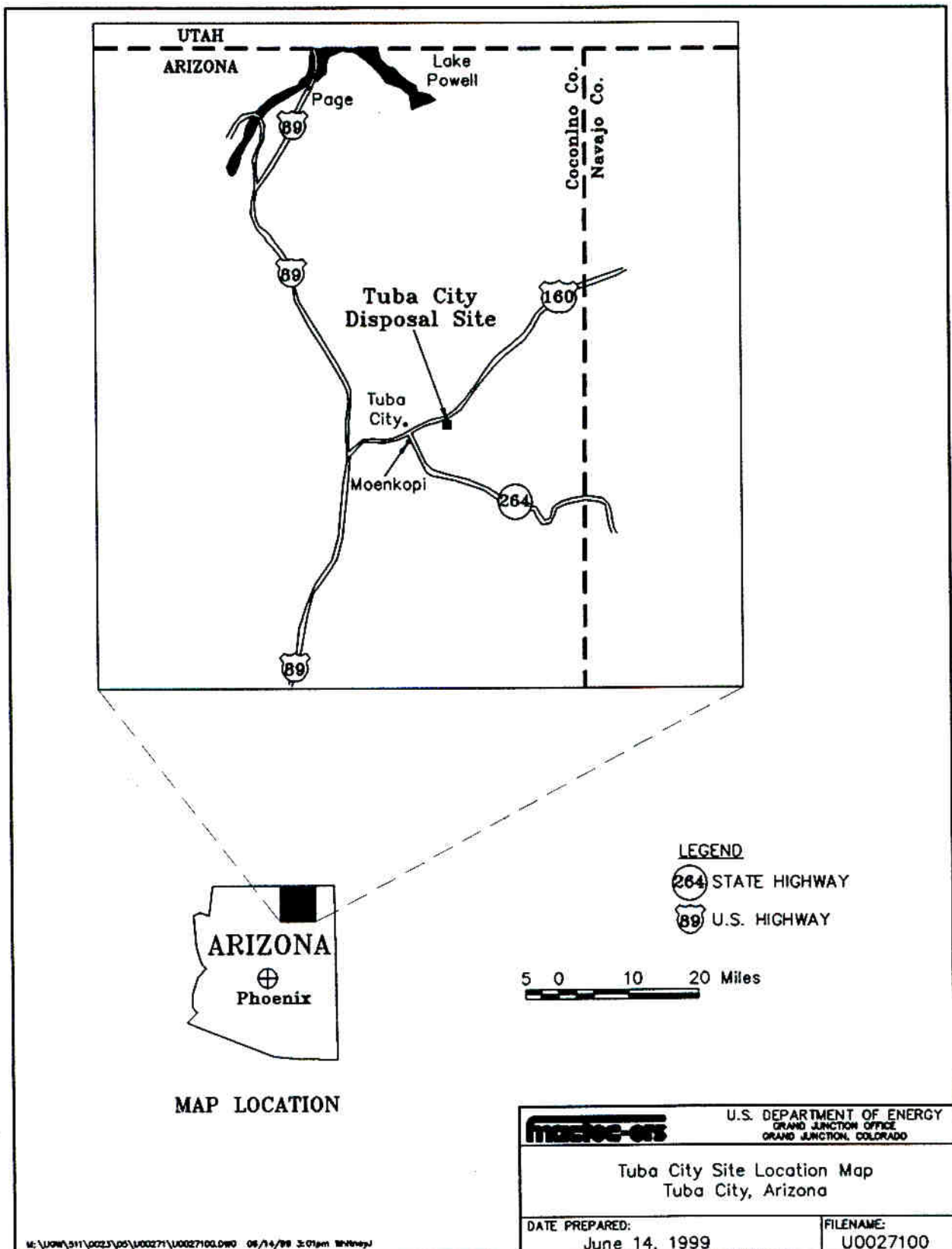hydrology for the site.
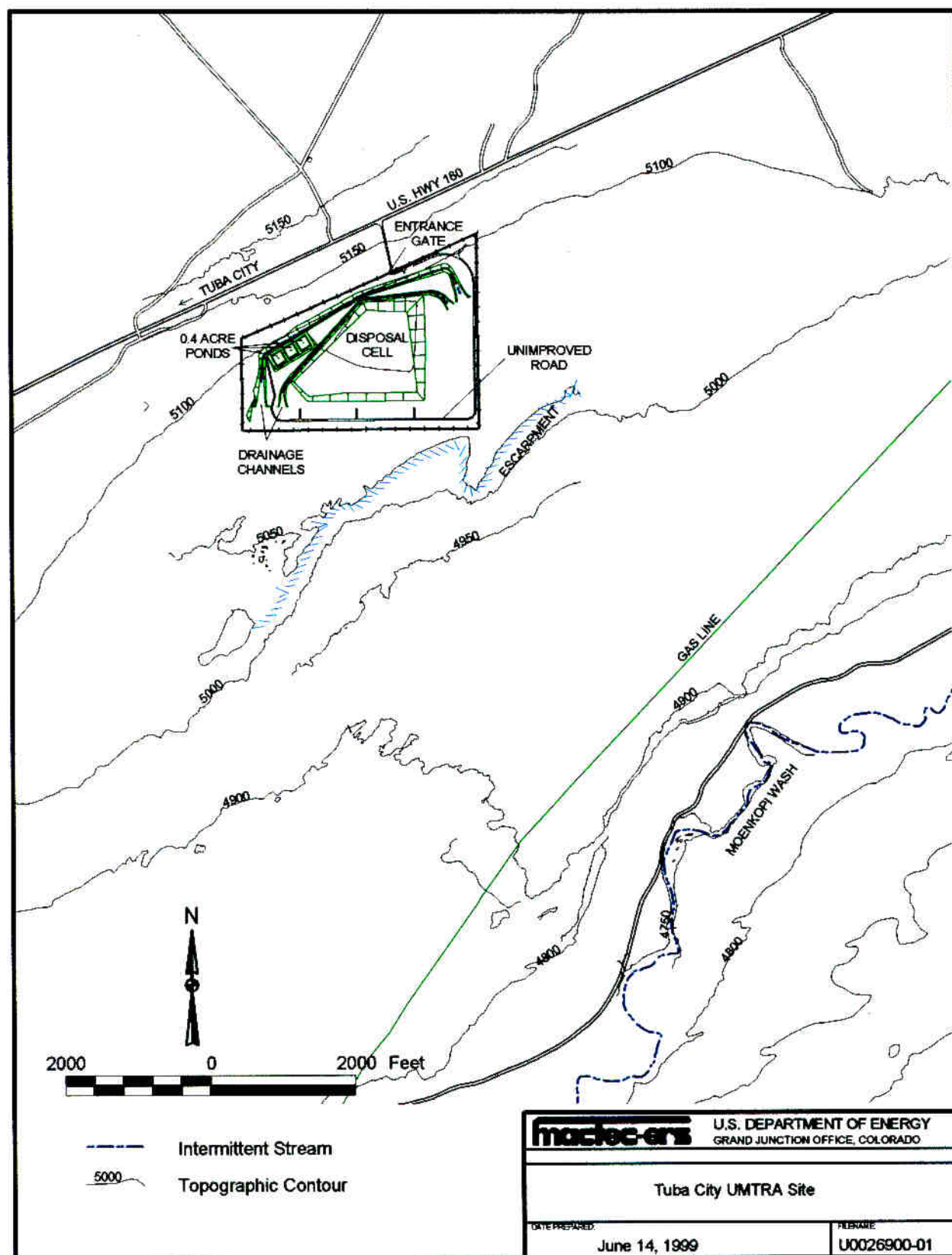
Figure 2-1. Site Location Map

Figure 2–2. Tuba City UMTRA Site

2.3.1 Hydrology

The main aquifer near the Tuba City site is the N-multiple aquifer system. On a regional scale, the N-aquifer is vast and encompasses all of the Navajo Sandstone deposits, including an intertonguing interval. The volume of water contained in the N-aquifer is approximately 5.9×10^{13} gallons; transmissivity ranges from 20 to 800 square feet per day. The estimated horizontal hydraulic conductivity, calculated using the total saturated thickness, ranges from 0.05 to 2.1 feet per day (ft/day) and averages 0.65 ft/day. The average hydraulic conductivity near the site is 0.5 ft/day. The average unconfined storage coefficient is 0.10 to 0.15.

Regionally, the aquifer obtains its recharge from rainfall and snowmelt throughout the 1,400 square mile area where the Navajo Sandstone is exposed. A small amount of recharge occurs as leakage from overlying confining beds. Estimated annual recharge to the aquifer is 13,000 acre-feet (Eychaner 1983). Discharge from the N-aquifer occurs as evapotranspiration to vegetation, direct discharge to springs and seeps along the axis of Moenkopi Wash, and discharge to Moenkopi Wash alluvium. The discharge to surface water from the N-aquifer is estimated to be about 5,300 acre-feet/year (Eychaner 1983).

The saturated thickness of the N-aquifer near the disposal cell is about 400 ft, but within 2,000 ft south of the disposal cell the aquifer thins rapidly towards the south. Depth to ground water also decreases rapidly over this reach, and phreatic vegetation becomes more abundant south of the disposal cell. Approximately 4,000 ft south of the site, seeps issue forth along cliff bands that border the incised valley of Moenkopi Wash. The observed vegetation and depth to ground water indicate that most ground water near the site exits the N-aquifer by evapotranspiration.

2.3.2 Water Quality

Table 2–1 shows background ground-water quality in the N-aquifer near the disposal cell. Samples were taken from well 901, located approximately 2,000 ft north of the site. Background water quality is good and has low concentrations of dissolved solids and metals. The water quality is suitable for all domestic uses.

Table 2–1. Background Water Quality of the N-Aquifer

Constituent	Concentration (mg/L)
Cadmium	< 0.001
Molybdenum	< 0.001
Nitrate	13
Selenium	0.0021
Strontium	0.31
Sulfate	19
Total Dissolved Solids	170
Uranium	0.002

Results from January 1997 sampling of well 901.

Moenkopi Wash is the dominant natural surface-water feature in the area. Near the village of Moenkopi the drainage area of Moenkopi Wash is 1,629 square miles. The average flow at the stream gauge located on the bridge on State Highway 264 near the village of Moenkopi is 4.4 cubic feet per second. Surface-water sampling of seeps draining to Moenkopi Wash indicate that contamination from the disposal cell has not migrated to the wash.

2.5 Ground-Water Contamination

2.5.1 Source of Contamination

The primary source of ground-water contamination in the N-aquifer near the site is water that drained from the tailings piles during operation of the mill (1956 through 1966). The rate of drainage from the evaporation ponds decreased significantly after 1966 and is now essentially complete. Uranium ore processing required 200 to 1,000 gallons of water per ton of ore processed. This water was discharged with the mill tailings as a slurry to evaporation ponds. The evaporation ponds were unlined; consequently, water that did not evaporate flowed downward to the N-aquifer. The water in the evaporation ponds contained high concentrations of dissolved constituents derived from the milling process: nitrate, sulfate, sodium, calcium, and uranium (although in lesser amounts). Site-related contamination in ground water has been detected 2,500 ft downgradient from the disposal site and to a depth of 86 ft below the water table.

Surface remediation may be the cause of a secondary source of contamination in the N-aquifer. Contaminated water from pore fluids may have migrated to the N-aquifer as a result of consolidation of lime tailings in the disposal cell and slow drainage of water used for engineered compaction during construction of the disposal cell. These two potential sources of contaminated water are known collectively as transient drainage. Based on hydrological modeling, the transient drainage component from consolidation of the slime tailings is about one percent (260,000 gallons) of the total transient drainage volume. It is relatively short-lived and drainage from the pore fluids may be complete. The modeling results also indicated that drainage water used from compaction is relatively long-lived. Modeling results showed that water used for compaction will reach the N-aquifer by unsaturated-flow, that the unsaturated-flow may exist for up to 1,000 years or more, and that it could contribute up to 37 million gallons over this period. The incremental rate of drainage from the disposal cell is predicted to be relatively slow and its volume is small compared to the volume of contaminated ground (estimated at 1,700 million gallons) and the volume of ground water that will pass under the site during the 1,000-year period. However, there is no way to validate the modeling results and there is considerable uncertainty regarding the actual rate of transient drainage. For example, the transient drainage may drain faster than what is predicted by the model. Another factor the model is unable to predict is the effect that high concentrations of contaminants in the transient drainage water will have on the concentrations in the ground water passing under the disposal cell. Even though the volume of transient drainage water is relatively small, its high concentrations of contaminants may cause concentrations in the ground water passing under the site to exceed allowable levels. Since there is no way to predict the actual effects that transient drainage will have on the concentration of contaminants in the ground water, long-term monitoring will be required.

The contaminants in the N-aquifer that exceed the standards in 40 CFR 192 are molybdenum, nitrate, selenium, and uranium. High levels of sulfate are also present in the ground water, and although sulfate is not a constituent included in 40 CFR 192, its concentration in the ground water is high enough to cause a potential health risk. Molybdenum only exceeded its 40 CFR 192 standard, a maximum concentration limit (MCL) of 0.1 milligrams per liter (mg/L), in one monitoring well in the most recent sampling (although it has exceeded the MCL at other monitoring wells in the past), so a plume map is not shown in this document. Plume maps showing the horizontal extent of contamination for nitrate, selenium, uranium, and sulfate are shown as Figure 2–3, Figure 2–4, Figure 2–5, and Figure 2–6, respectively. Nitrate and sulfate form the largest plumes, extending approximately 2,500 ft from the southwest corner of the disposal cell. Within the N-aquifer, contaminant concentrations generally appear to decrease with depth, although at some locations, concentrations increase with depth. Existing monitoring wells have shown contamination to depths as great as 86 ft below the water table.

Analytical results of samples from wells near the disposal cell show that uranium concentrations have increased in wells on the east side of the disposal cell and have remained steady in other wells near the cell. Sulfate and nitrate concentrations have risen significantly in wells on the southwest side of the disposal cell and have remained constant in other wells near the cell.

Thirteen other contaminants attributable to milling activities were found in the ground water at concentrations above background: ammonium, cadmium, calcium, chloride, chromium, iron, magnesium, manganese, potassium, sodium, strontium, tin, and zinc. However, the concentrations of these contaminants do not pose a potential health risk. Lead has been found in concentrations that exceed background but below the MCL of 0.05 mg/L. However, the elevated lead levels are not attributable to milling activities.

Estimates of the volume of contaminated ground water in the nitrate, sulfate, and uranium plumes are shown in Table 2–2. The estimates are conservative and probably overstate the volume because contamination was assumed to extend uniformly from the water table to a depth of 86 ft. Actual volumes may be closer to one-half the volumes given in the table. The volumes given in the table should be considered estimates of the maximum potential plume volumes.

Table 2–2. Volumes of Contaminated Ground Water

Contaminant	Concentration (mg/L)	Area (ft^2)	Volume (gallons)[a]
Nitrate	44	1.6×10^7	1.7×10^9
Sulfate	250	8.9×10^6	1.4×10^9
Uranium	0.044	4.8×10^6	7.8×10^8

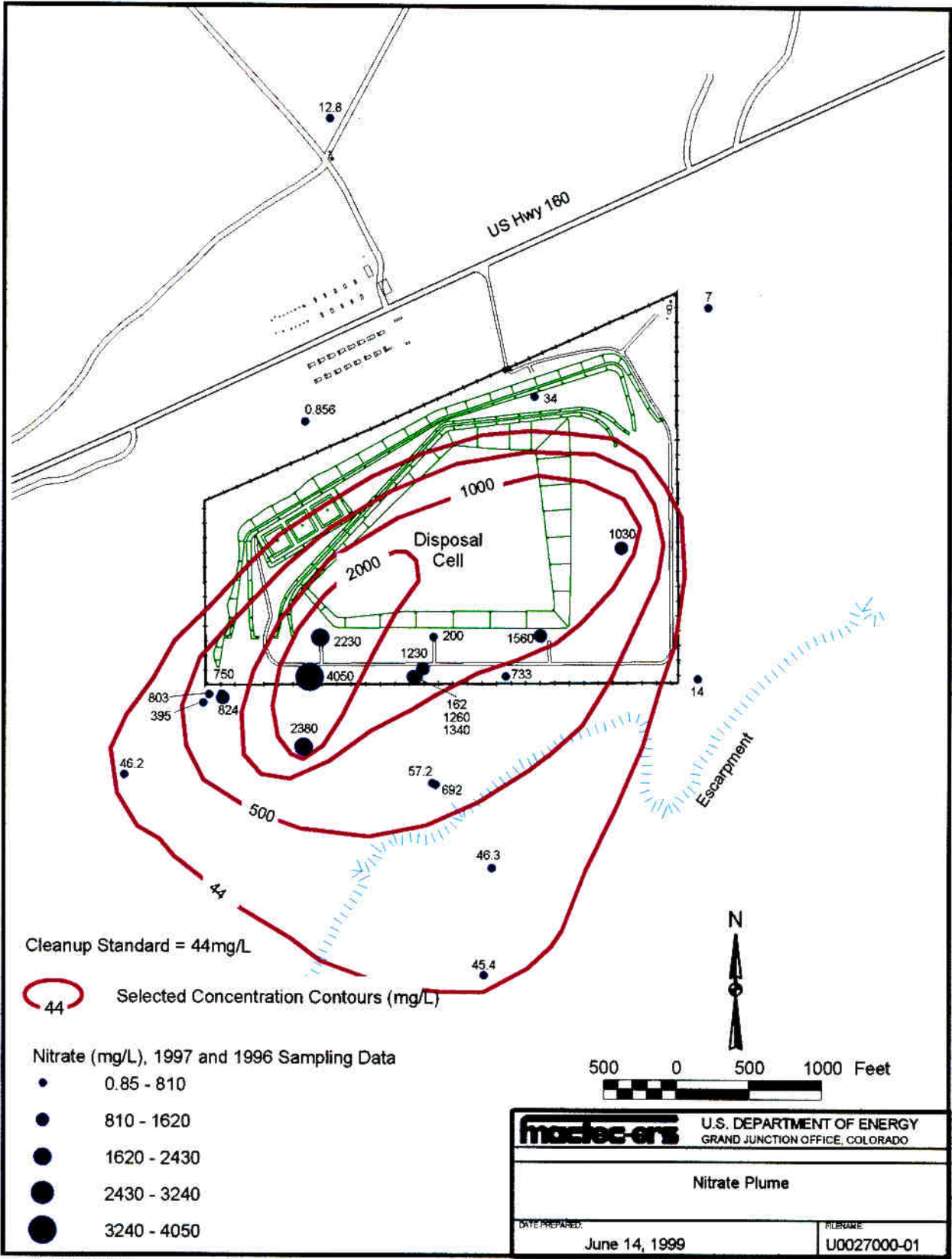[a]Based on saturated thickness of 86 ft and porosity of 0.25.
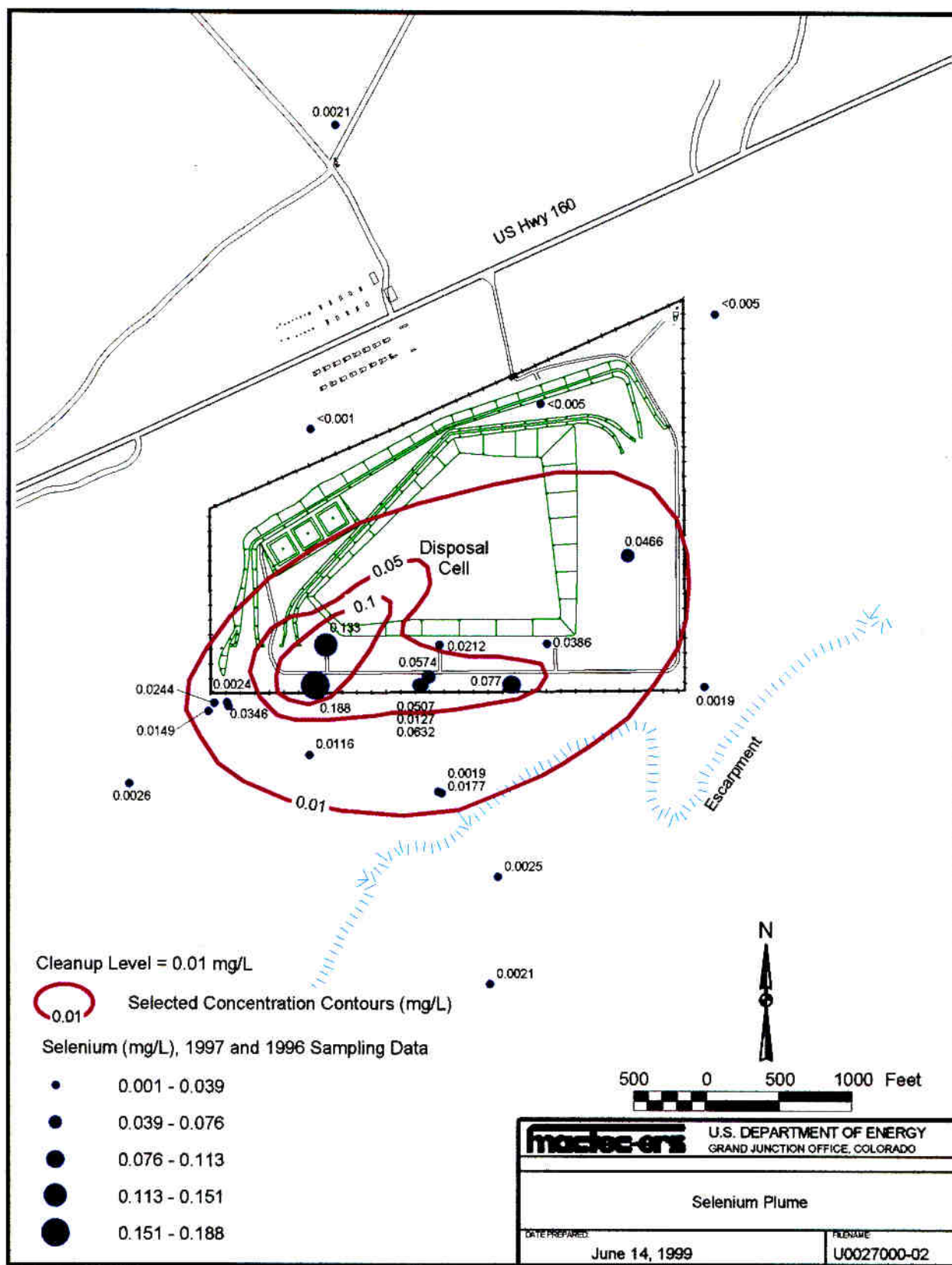
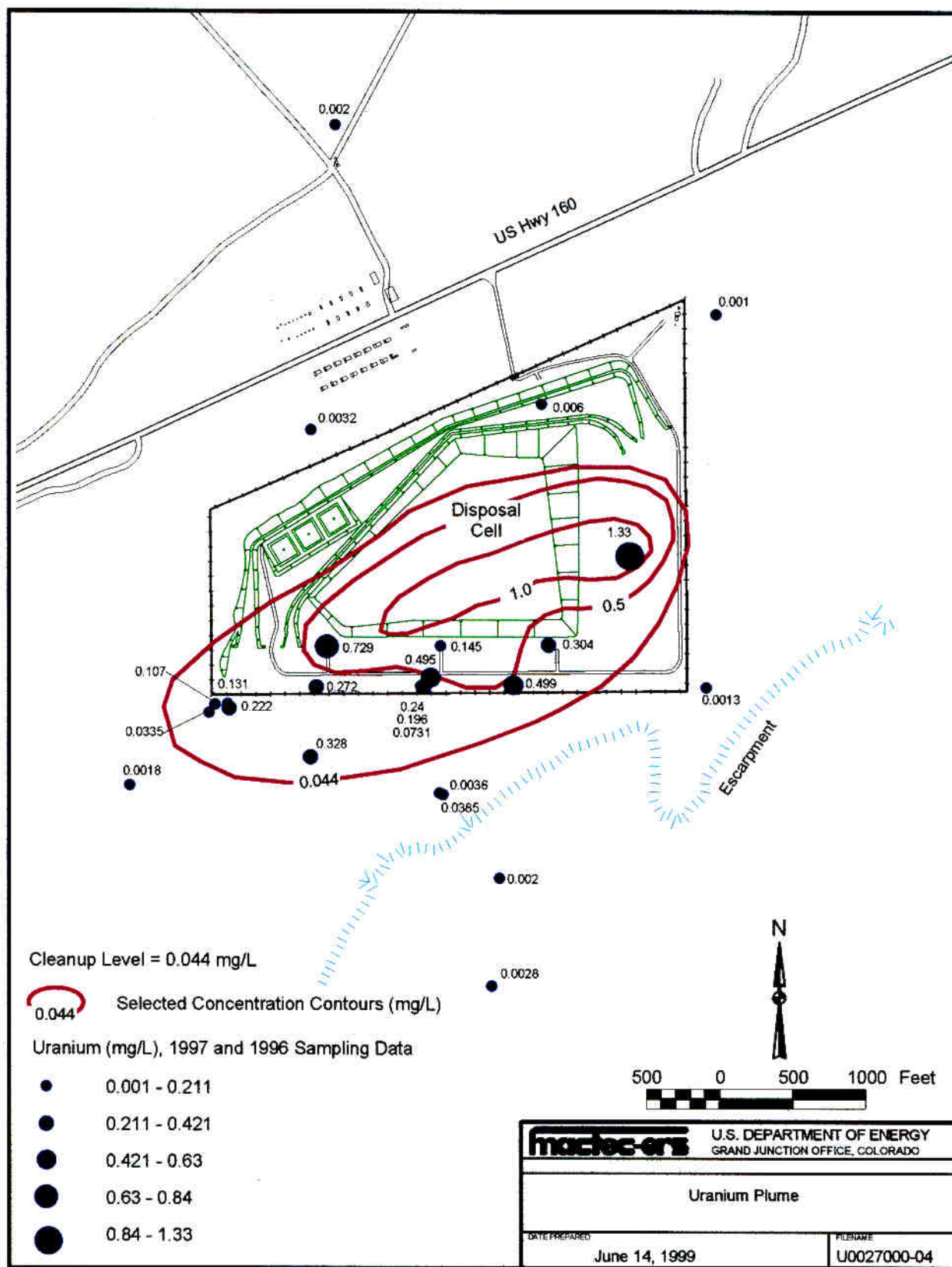Figure 2–3. Nitrate Plume

Figure 2–4. Selenium Plume
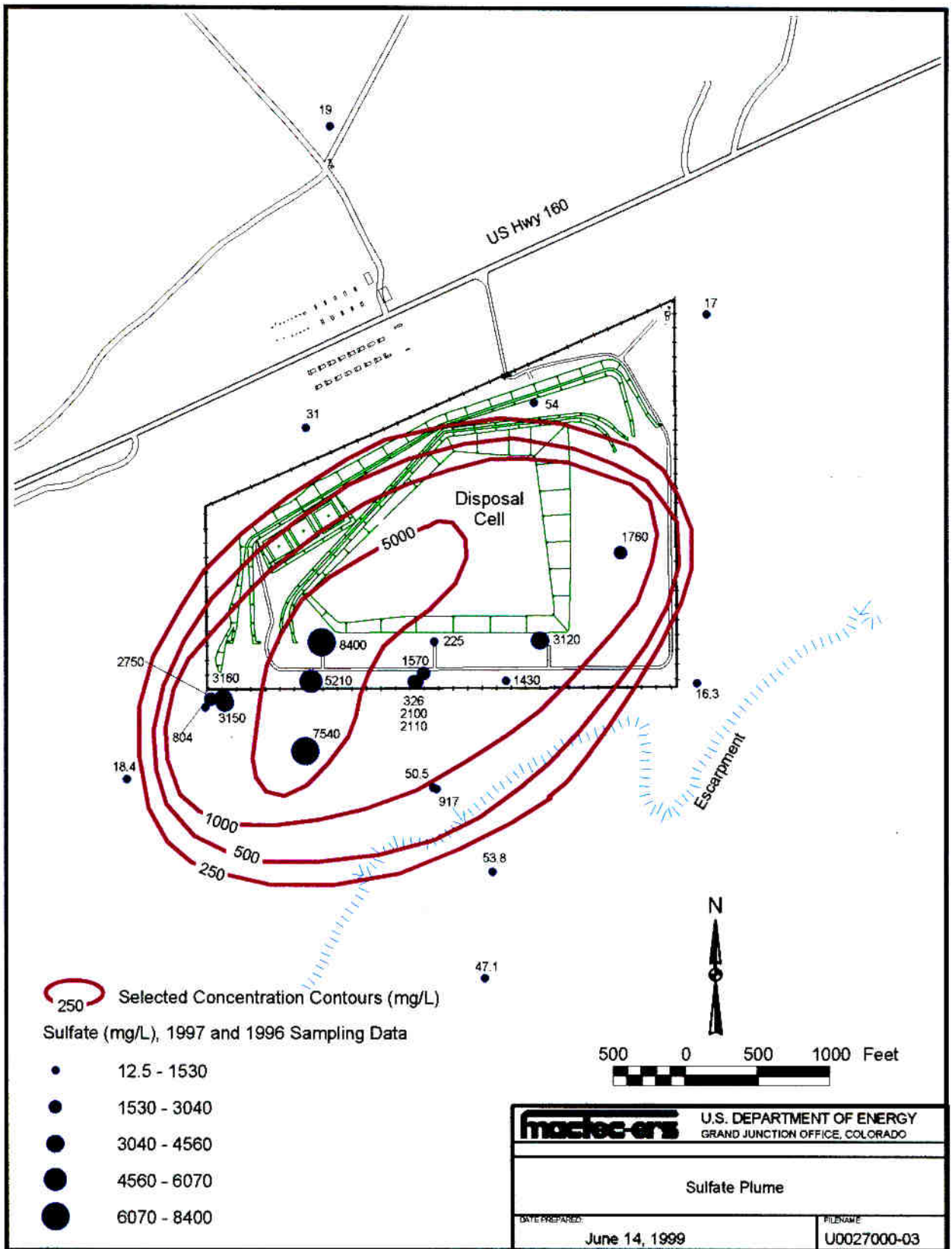
Figure 2–5. Uranium Plume

Figure 2–6. Sulfate Plume

3.0 Compliance Plan

This section describes the proposed ground-water compliance strategy for contaminants in the ground water that are attributable to milling activities. It also explains the application of site-specific data to the ground-water compliance selection framework. Ground-water compliance decisions at the Tuba City site were made by using the compliance selection framework shown in Figure 3–1. This compliance selection framework is documented in Section 2.0 of the PEIS (DOE 1996) and is supported by the PEIS Record of Decision (DOE 1997).
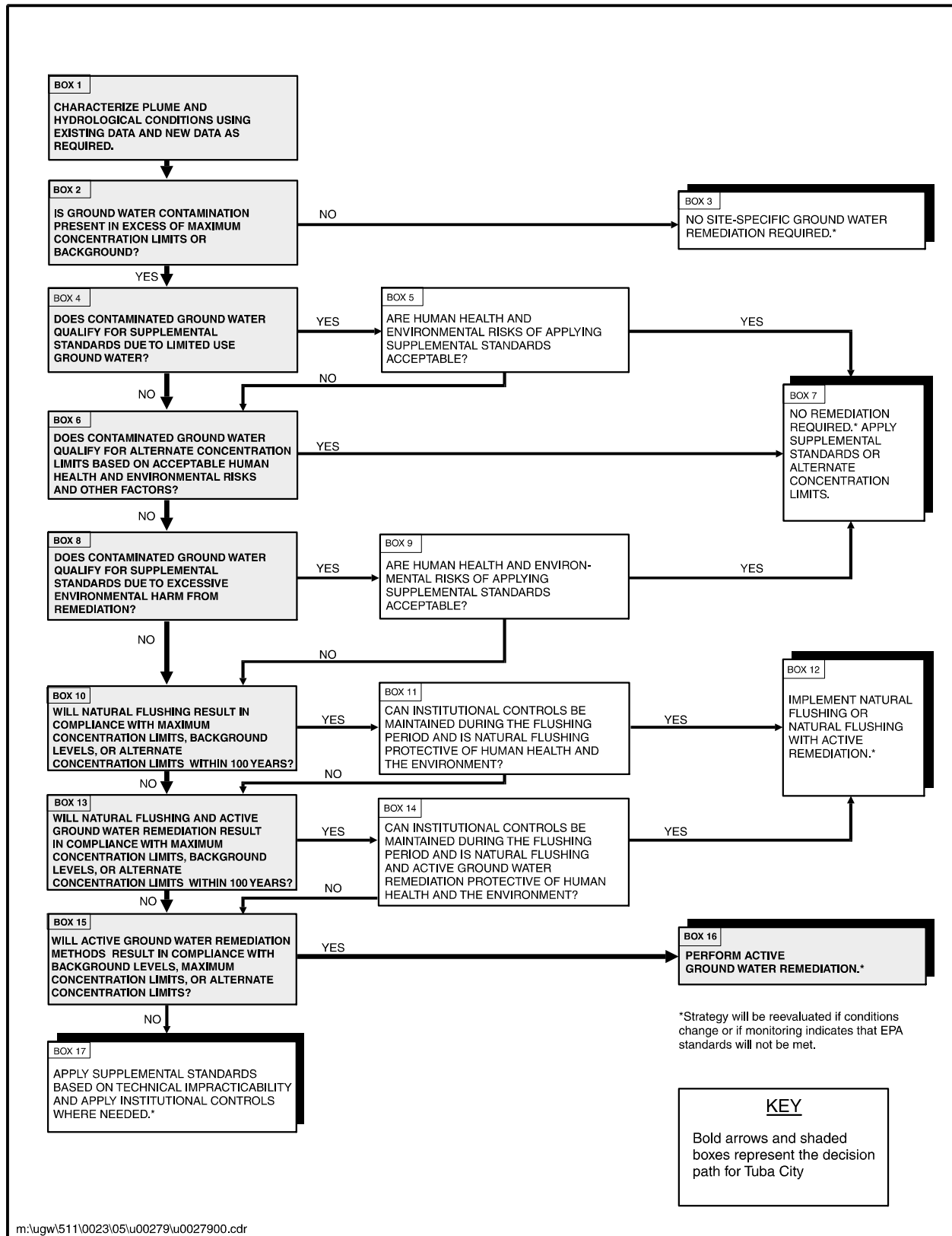
3.1 UMTRA Ground-Water Compliance Strategies

Eighteen contaminants attributable to milling activities were identified in the ground water at concentrations that exceeded background: ammonium, cadmium, calcium, chloride, chromium, iron, magnesium, manganese, molybdenum, nitrate, potassium, selenium, sodium, strontium, sulfate, tin, uranium, and zinc. Section 6.0 of the Site Observational Work Plan (DOE 1998) evaluated whether the concentrations of these 18 contaminants caused excess potential risk to human health or the environment. Six of the 18 contaminants (cadmium, chromium, molybdenum, nitrate, selenium, and uranium) are regulated by 40 CFR 192.

No remediation is the compliance strategy for 13 of the 18 contaminants: ammonium, cadmium, calcium, chloride, chromium, iron, magnesium, manganese, potassium, sodium, strontium, tin, and zinc. The no-remediation strategy is appropriate because these contaminants do not exceed their MCLs or cause excess potential risk. The following discussion presents the reasoning for the no-remediation strategy, based on the process described in the PEIS (DOE 1996) and shown graphically in Figure 3–1.

Two of the 13 contaminants (cadmium and chromium) have MCLs established in 40 CFR 192. However, the concentrations of cadmium and chromium do not exceed their MCLs (box 2 in Figure 3–1), and therefore the ground-water compliance strategy for these contaminants is no remediation (box 3 in Figure 3–1).

Eleven of the 13 contaminants (ammonium, calcium, chloride, iron, magnesium, manganese, potassium, sodium, strontium, tin, and zinc) are not regulated by 40 CFR 192 and therefore do not have MCLs but do exceed background concentrations (box 2 in Figure 3–1). Because these contaminants exceed their background concentrations, evaluation of the criterion in box 4 in Figure 3–1 is required. The criterion in box 4 evaluates whether supplemental standards can be applied based on limited-use ground water. Ground water at the Tuba City site does not meet the criteria for limited-use ground water. For ground water to be classified as limited use, the total dissolved solids (TDS) concentration must exceed 10,000 mg/L, there must be widespread ambient contamination that cannot be cleaned up using treatment methods reasonably employed in public water-supply systems, or the sustained yield of ground water must be less than 150 gallons per day. The ground water at Tuba City does not meet any of these criteria.

Therefore, the next step is to evaluate the criterion in box 6 in Figure 3–1. The health effects of these 11 contaminants were examined and found not to cause excess potential risk. Since no

BOX 1
CHARACTERIZE PLUME AND HYDROLOGICAL CONDITIONS USING EXISTING DATA AND NEW DATA AS REQUIRED.

BOX 2
IS GROUND WATER CONTAMINATION PRESENT IN EXCESS OF MAXIMUM CONCENTRATION LIMITS OR BACKGROUND?

NO →

BOX 3
NO SITE-SPECIFIC GROUND WATER REMEDIATION REQUIRED.*

YES ↓

BOX 4
DOES CONTAMINATED GROUND WATER QUALIFY FOR SUPPLEMENTAL STANDARDS DUE TO LIMITED USE GROUND WATER?

YES →

BOX 5
ARE HUMAN HEALTH AND ENVIRONMENTAL RISKS OF APPLYING SUPPLEMENTAL STANDARDS ACCEPTABLE?

YES →

NO

NO ↓

BOX 6
DOES CONTAMINATED GROUND WATER QUALIFY FOR ALTERNATE CONCENTRATION LIMITS BASED ON ACCEPTABLE HUMAN HEALTH AND ENVIRONMENTAL RISKS AND OTHER FACTORS?

YES →

BOX 7
NO REMEDIATION REQUIRED.* APPLY SUPPLEMENTAL STANDARDS OR ALTERNATE CONCENTRATION LIMITS.

NO ↓

BOX 8
DOES CONTAMINATED GROUND WATER QUALIFY FOR SUPPLEMENTAL STANDARDS DUE TO EXCESSIVE ENVIRONMENTAL HARM FROM REMEDIATION?

YES →

BOX 9
ARE HUMAN HEALTH AND ENVIRONMENTAL RISKS OF APPLYING SUPPLEMENTAL STANDARDS ACCEPTABLE?

YES →

NO

NO ↓

BOX 10
WILL NATURAL FLUSHING RESULT IN COMPLIANCE WITH MAXIMUM CONCENTRATION LIMITS, BACKGROUND LEVELS, OR ALTERNATE CONCENTRATION LIMITS WITHIN 100 YEARS?

YES →

BOX 11
CAN INSTITUTIONAL CONTROLS BE MAINTAINED DURING THE FLUSHING PERIOD AND IS NATURAL FLUSHING PROTECTIVE OF HUMAN HEALTH AND THE ENVIRONMENT?

YES →

BOX 12
IMPLEMENT NATURAL FLUSHING OR NATURAL FLUSHING WITH ACTIVE REMEDIATION.*

NO

NO ↓

BOX 13
WILL NATURAL FLUSHING AND ACTIVE GROUND WATER REMEDIATION RESULT IN COMPLIANCE WITH MAXIMUM CONCENTRATION LIMITS, BACKGROUND LEVELS, OR ALTERNATE CONCENTRATION LIMITS WITHIN 100 YEARS?

YES →

BOX 14
CAN INSTITUTIONAL CONTROLS BE MAINTAINED DURING THE FLUSHING PERIOD AND IS NATURAL FLUSHING AND ACTIVE GROUND WATER REMEDIATION PROTECTIVE OF HUMAN HEALTH AND THE ENVIRONMENT?

YES →

NO

NO ↓

BOX 15
WILL ACTIVE GROUND WATER REMEDIATION METHODS RESULT IN COMPLIANCE WITH BACKGROUND LEVELS, MAXIMUM CONCENTRATION LIMITS, OR ALTERNATE CONCENTRATION LIMITS?

YES →

BOX 16
PERFORM ACTIVE GROUND WATER REMEDIATION.*

NO ↓

BOX 17
APPLY SUPPLEMENTAL STANDARDS BASED ON TECHNICAL IMPRACTICABILITY AND APPLY INSTITUTIONAL CONTROLS WHERE NEEDED.*

*Strategy will be reevaluated if conditions change or if monitoring indicates that EPA standards will not be met.

KEY

Bold arrows and shaded boxes represent the decision path for Tuba City

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measures are required to mitigate the potential risk associated with these contaminants and they are not regulated by 40 CFR 192, a compliance strategy will not be developed for these constituents (box 7 in Figure 3–1).

Active remediation is the compliance strategy for five of the 18 contaminants (molybdenum, nitrate, selenium, uranium, and sulfate). Four contaminants (molybdenum, nitrate, selenium, and uranium) are present in the ground water at concentrations that exceed their respective MCLs. One contaminant, sulfate, is not regulated by 40 CFR 192 but is present at concentrations that cause an excess potential risk. The following discussion presents the justification for selecting active remediation for these contaminants. The discussion is based on the process shown in Figure 3–1.

Evaluation of the criterion in box 2 of Figure 3–1 shows that the concentrations of molybdenum, nitrate, selenium, and uranium in the ground water beneath and downgradient from the site exceed their MCLs and that sulfate exceeds its background concentration. Therefore, evaluation of the criterion in box 4 in Figure 3–1 is required. As discussed previously, ground water at the Tuba City site does not qualify for supplemental standards based on limited-use ground water.

The ground water at the Tuba City site also does not meet the criterion in box 6 in Figure 3–1. ACLs potentially could be established for wells near the disposal site if the concentrations of contaminants at the fence line of the site, the area where someone could be exposed to the ground water, were less than MCLs or did not present potential excess risks and were not expected to increase. This is not the case at the Tuba City site because concentrations of the five contaminants in wells outside the fenced area of the site exceed MCLs or health-based levels.

The next step (box 8 in Figure 3–1) evaluates whether there would be excessive environmental harm from remediation of the ground water. An example in which this would be applicable is if the remediation dewatered the entire aquifer or dewatered a wetlands that was a ground-water discharge area. Remediation of the ground water at the Tuba City site is not expected to cause excessive environmental harm and, therefore, the criterion in box 8 of Figure 3–1 is not applicable at the Tuba City site.

The feasibility of natural attenuation, also known as natural flushing, is evaluated next (box 10 in Figure 3–1). With the natural gradient, approximately 220 years are required to flush one pore volume through the contaminated area. The regulatory time limit for natural flushing is 100 years, assuming institutional controls can be maintained for that period. Therefore, natural flushing is not a feasible regulatory strategy.

Since natural flushing by itself cannot achieve cleanup levels within 100 years, a combination of active remediation and natural flushing is considered (box 13 in Figure 3–1). Because the time periods for natural flushing are so long (i.e., up to 220 years for one pore volume), a combination of natural flushing and active remediation probably will not result in compliance for contaminants such as uranium and nitrate that have high concentrations relative to their MCLs.

Active ground-water remediation (box 15 in Figure 3–1) is evaluated next to determine if it will result in compliance with the standards. Available information suggests that compliance with the standards may be achieved through active remediation and, therefore, the remediation strategy is

to perform active remediation (box 16 in Figure 3–1) for molybdenum, nitrate, selenium, uranium, and sulfate. In addition to these contaminants, the Navajo Nation requested cleanup goals for TDS, chloride, pH, and corrosivity and a cleanup goal for sulfate based on aesthetics rather than health concerns. These additional cleanup goals are discussed in the next section.

3.2 Remediation Standards and Goals

The general requirements for contaminant levels in the ground water at UMTRA sites are specified in 40 CFR 192. The contaminants of concern at the Tuba City site that have standards specified in Table 1 of 40 CFR 192.04 are nitrate, molybdenum, selenium, and uranium. Table 1 does not specify ground-water restoration standards for other contaminants of concern that exceed background concentrations.

The Navajo Nation, in a letter dated September 18, 1997, proposed secondary cleanup standards for restoration of ground water at the Tuba City site that included additional contaminants that are not listed in 40 CFR 192. DOE considered the request and will incorporate the suggested secondary cleanup standards as goals for aquifer restoration and treatment of extracted ground water.

Cleanup levels for the aquifer were divided into aquifer restoration standards (requirements of 40 CFR 192) and aquifer restoration goals (cleanup standards requested by the Navajo Nation but not required by 40 CFR 192). Aquifer restoration goals are cleanup levels that are not based on enforceable standards. However, DOE will make every reasonable effort to restore the aquifer so as to comply with these cleanup goals. The restoration standards and goals for the aquifer are listed in Table 3–1. The Navajo Nation also requested that treatment of extracted ground water be held to a sodium standard of 20 mg/L.

Table 3–1. Aquifer Restoration Standards and Goals

Contaminant	Cleanup Level	Concentrations in the Plume
Aquifer Restoration Standards (required by 40 CFR 192)		
Nitrate	10 mg/L as N (44 mg/L as NO_3^-)	840–1,500 mg/L
Molybdenum	0.10 mg/L	0.01–0.58 mg/L
Selenium	0.01 mg/L	0.01–0.10 mg/L
Uranium	30 pCi/L (0.044 mg/L) U-234 & U-238	0.3–0.6 mg/L
Aquifer Restoration Goals (requested by the Navajo Nation)		
TDS	500 mg/L	3,500–10,000 mg/L
Sulfate	250 mg/L	1,700–3,500 mg/L
Chloride	250 mg/L	20–440 mg/L
pH	6.5–8.5	6.3–7.6
Corrosivity	noncorrosive	not applicable

4.0 Selected Remedial Action

The remediation method for the Tuba City site was selected after evaluation of several remediation alternatives. Alternatives were developed by dividing the remediation process into two components: extraction and disposal of the ground water and treatment of the extracted ground water. Two pumping alternatives were developed to address extraction and disposal of the ground water. One alternative required vertical wells for extraction and solar evaporation for disposal of the ground water. The other pumping alternative required vertical wells for extraction and a combination of vertical injection wells and an infiltration trench for disposal of treated ground water. Four treatment alternatives were developed and evaluated. The treatment alternatives used spray evaporation, distillation, chemical treatment with biological denitrification, and nanofiltration with biological denitrification to treat the extracted ground water. The pumping and treatment alternatives were evaluated on effectiveness, implementability, and cost.

The selected remediation method for active restoration at the Tuba City site combines the pumping alternative that uses extraction and injection wells with an infiltration trench with the treatment alternative that uses distillation. After evaluation, these pumping and treatment alternatives had the best balance of effectiveness, implementability, and cost. The specific components of the selected pumping and treatment method are discussed below.

4.1 Selected Pumping Method

The selected pumping method has two primary objectives: (1) extract contaminated ground water from the aquifer at a rate that will generate two pore volumes of the uranium plume within 20 years, and (2) contain the contamination to an area within the existing plume. Containment of the plume can be achieved by injecting the treated ground water along the edges of the plume to control its downgradient migration and redirect uncontaminated ground water around the plume. Extracting two pore volumes of the uranium plume (i.e., 2 times 780 million gallons) within 20 years requires a continuous extraction rate of approximately 150 gallons per minute (gpm). The anticipated extraction rate for the selected pumping method is approximately 200 gpm once the system reaches its maximum capacity.

Laboratory testing on rock cores collected from inside and outside the plume area shows that chemical sorption on the solid phase is minor. Moreover, the ground water is oxygenated and there is a high concentration of carbonate anions in the plume. This causes uranium to be in the hexavalent state as uranyl dicarbonate. These factors contribute to a low distribution coefficient (K_d) for uranium at the site; the average K_d for uranium is about 0.1 mL/g. This value implies that most uranium would be removed from the most permeable areas with the first pore volume. Most of the anion constituents within the plume (i.e., nitrate and sulfate) would also be flushed from the most permeable areas with the first pore volume since they are also almost entirely in solution. Based on these considerations, sorption of contaminants likely will not affect the ability to achieve ground-water protection standards for nitrate, uranium, and sulfate, and extraction of two pore volumes of the uranium plume is a reasonable estimate of the volume required to achieve the standards for these contaminants. Heterogeneities of the aquifer will affect how much water must be extracted to meet the standards but this effect cannot be quantified.

The initial plans for the pumping system include 50 to 70 extraction wells, 30 to 40 injection wells, an infiltration trench approximately 2,400 ft long along the north side of the disposal cell, and piping and valves to convey ground water from the extraction wells to the treatment system and treated water from the treatment system to the injection wells and infiltration trench. Extraction and injection rates for each well are expected to vary from 0.5 gpm to 6 gpm. The flow to the infiltration trench is expected to be about 50 percent of the total treatment rate with the remainder of the water going to the injection wells. However, the infiltration trench is designed to handle up to the entire distillate capacity of the treatment system if there is excess water that will not readily flow into the injection wells. The number of extraction and injection wells is only an initial estimate. The final number will be dependent on additional site information obtained during remediation. However, the total extraction rate and the total injection rate to and from the well field will be balanced (i.e., the extraction rate will equal the injection rate plus the brine generation rate).

Two phases are planned for implementation of the extraction and injection wells. Figure 4–1 shows a conceptual layout for the Phase I extraction wells, injection wells, and infiltration trench. The strategy for Phase I extracts ground water from the most contaminated areas of the plume and contains the down-gradient movement of the plume. Extraction wells are planned along the southern edge of the disposal cell, southwest of the disposal cell in an area of high nitrate concentrations, and east of the disposal cell where uranium concentrations are highest. Injection wells are planned near the extraction wells to enhance the sustainable extraction rates and in areas outside the plume to stop its down-gradient movement. The Phase I implementation also includes an infiltration trench located north of the disposal cell. The purpose of the infiltration trench is to help flush contamination under the disposal cell to the extraction wells located just south of the disposal cell.

Phase II extraction and injection wells will be located to complete the remediation. Figure 4–2 shows a conceptual layout for the full implementation of all extraction wells, injection wells, and the infiltration trench. As shown in Figure 4–2, the current plan calls for no extraction or injection wells in the low permeability areas where extraction of ground water is not feasible. The locations of the low permeability areas have been predicted from calibration of the flow model. However, the low permeability areas will be better defined during evaluation of the system after the installation of the Phase I wells and prior to the installation of the Phase II wells. Also, the number and locations of the extraction and injection wells planned for Phase II will be revised based on information learned during Phase I.

4.2 Selected Treatment Method

The selected method for treating the extracted ground water at the Tuba City site is distillation, also known as mechanical evaporation and recondensation. Distillation meets or exceeds the treatment standards and goals, provides the highest quality of treated ground water, and has a net present cost comparable to the other active treatment methods. Effluent from the distillation treatment process will be injected back into the aquifer, which will help meet the standards specified in 40 CFR 192 and the cleanup goals requested by the Navajo Nation.
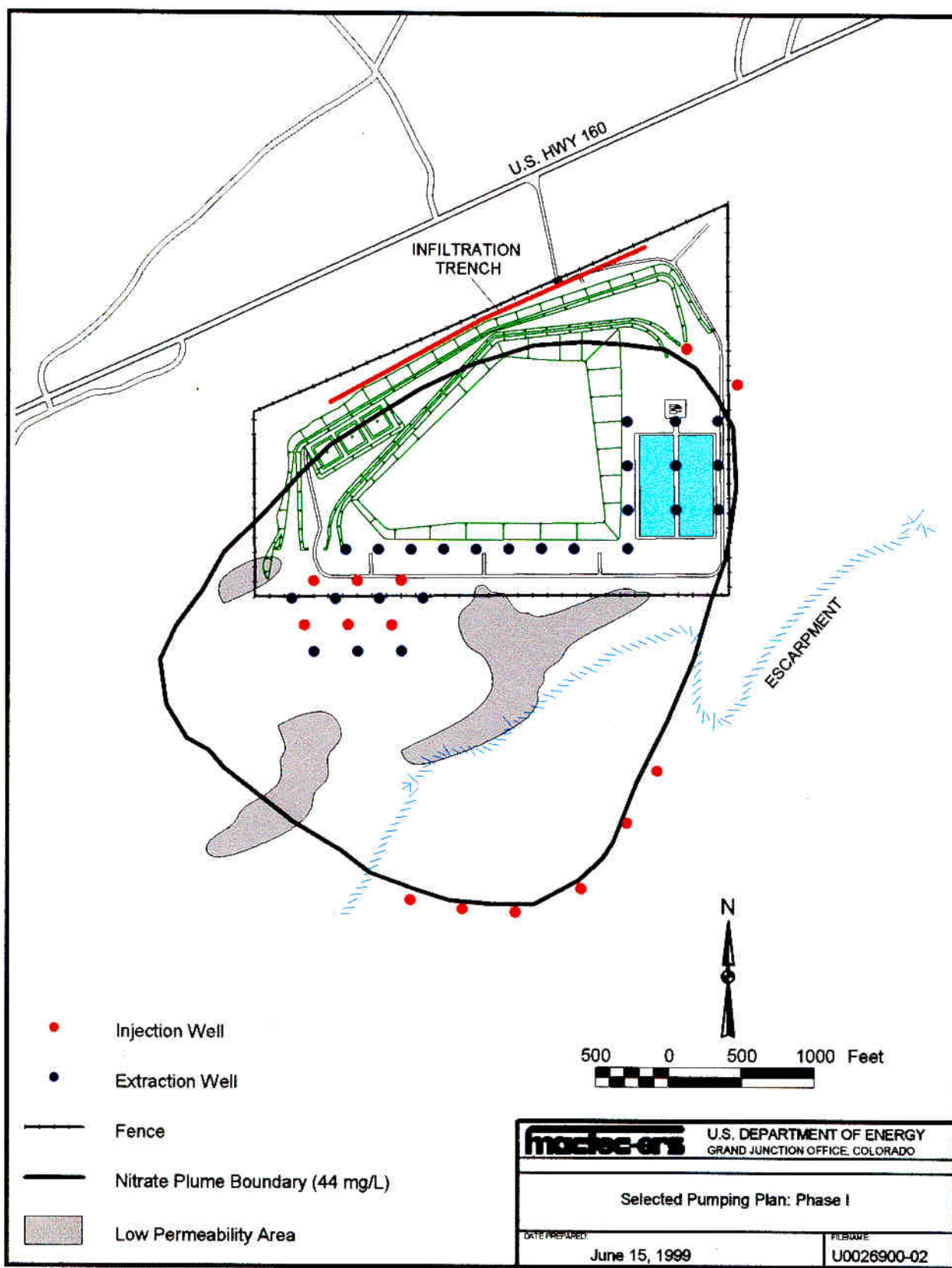
Figure 4–1. Phase I Implementation of the Selected Pumping Method
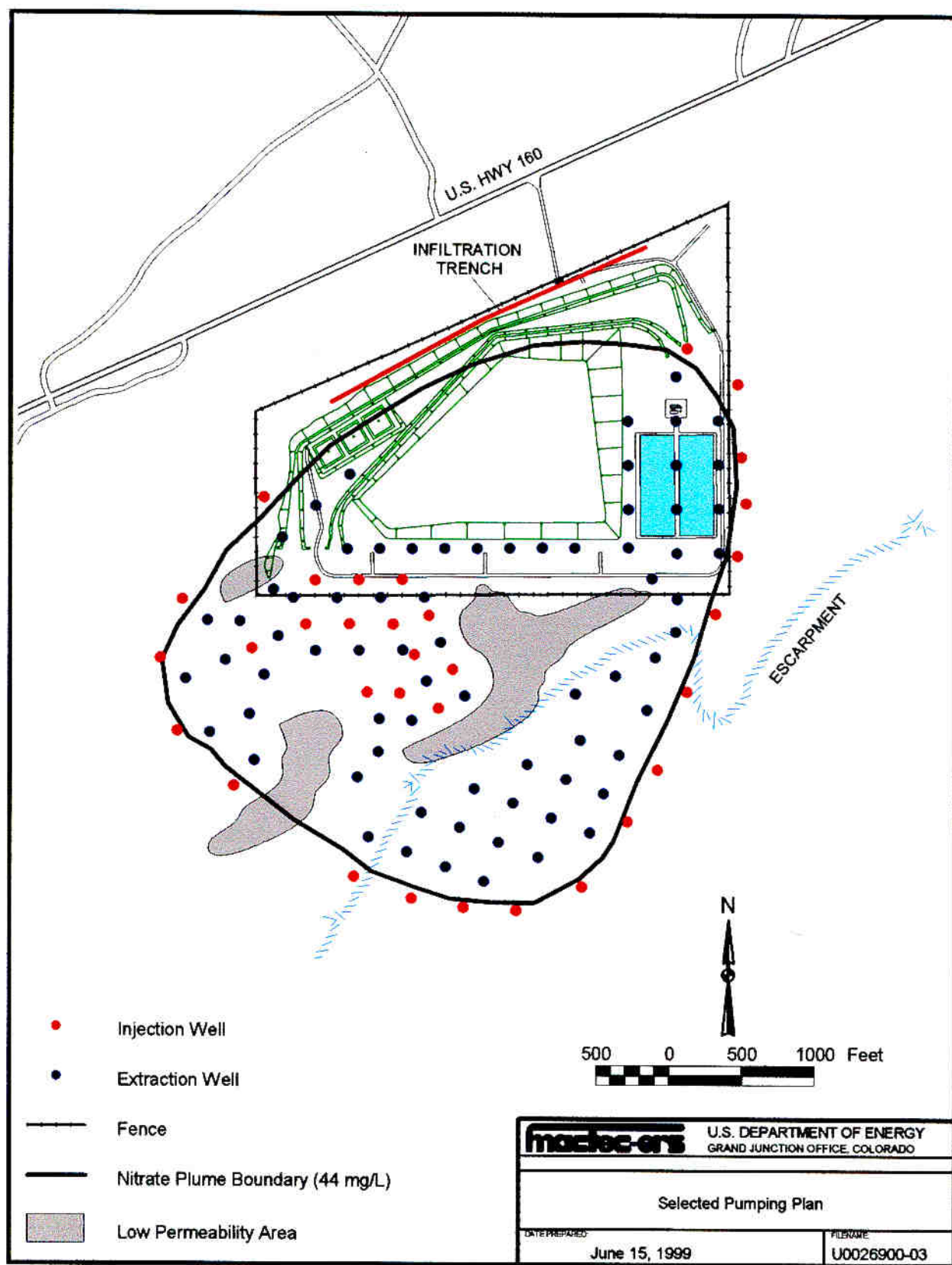
Figure 4–2. Phase II Implementation of the Selected Pumping Method

The beginning of the treatment system is the influent tank, with a capacity of approximately 20,000 gallons, which will be located adjacent to the treatment system. Extracted ground water will be pumped from the extraction wells to the influent tank. From the influent tank, contaminated ground water will be pumped to a pretreatment skid where acid and antiscalant will be added to the water. The addition of acid will convert calcium carbonate in the water to carbon dioxide gas, preventing the precipitation of calcium carbonate in the treatment unit. Sulfuric acid will be used, both for safety reasons, sulfuric acid does not emit harmful or corrosive fumes in storage, and for process reasons, because the sulfate will enhance the formation of calcium sulfate in the treatment unit. The antiscalant will be added in very low concentrations (3 parts per million or less) to minimize buildup of solids on the heat-transfer surfaces. The antiscalant is expected to concentrate in the brine. Once the operation of the treatment system has stabilized during Phase I operations, DOE will evaluate the feasibility of reducing the antiscalant dosage.

Effluent from the pretreatment skid will be pumped directly to the distillation unit for treatment. The treatment units will use a falling-film distillation process coupled with a vapor-recompression recondensation and energy conservation technology. Figure 4–3 shows a typical process flow diagram for a distillation unit and Figure 4–4 shows the layout of the components of the treatment system. The treatment units will be instrumented to permit continuous operation with remote monitoring capability. Effluent from the treatment units is expected to have a TDS concentration of 10 mg/L or less.

The treatment units will produce treated water and a concentrated brine that will contain the contaminants and other dissolved solids. The volume of the brine is expected to average 5 percent or less of the total influent volume. It will be pumped to one or more double-lined evaporation ponds for final concentration of the solids. The evaporation ponds will be double-lined and will be equipped with a leachate collection system. In the evaporation ponds, water from the brine will be evaporated by solar evaporation, and the remaining sludge will be collected and disposed of at a repository designed for residual radioactive material. The ponds will be sized to hold all of the sludge that will be produced during the remediation, so that they will only need to be cleaned out at the conclusion of the remediation project. During most of the year, the ponds will be covered with water. Because of the high salt content of the sludge, the surface when dry will be covered with a hard crust which will minimize wind losses. If needed, water will be added to the dry salt to prevent wind erosion.

The treated water from the evaporation system should average 95 percent or more of the total influent volume. All treated water will be pumped to the 10,000-gallon distillate storage tank. From the distillate tank, the treated ground water will flow by gravity into the aquifer through injection wells and the infiltration trench.

4.3 Remediation Approach

DOE's main criterion in implementing the Tuba City remediation is to reach the aquifer restoration standards for all contaminants of concern throughout the plume. The remediation system is planned to be implemented in two phases: Phase I and Phase II. The implementation will use the observational approach, in which the number of extraction wells will be increased with capture-zone analysis, optimization modeling studies, and monitoring. Figure 4–5 displays a summary of the implementation plan. The figure shows two implementation phases but an

additional phase (or phases) may be needed if funding limitations or technical constraints limit the planned scale-up.
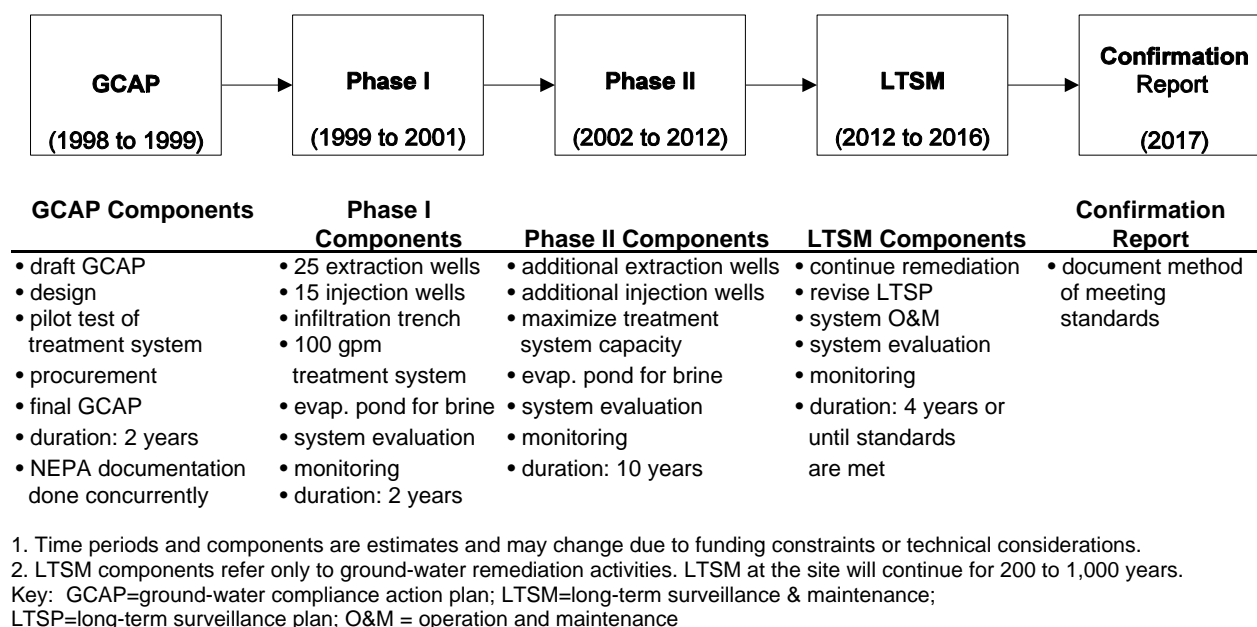
GCAP	Phase I	Phase II	LTSM	Confirmation Report
(1998 to 1999)	(1999 to 2001)	(2002 to 2012)	(2012 to 2016)	(2017)

GCAP Components	Phase I Components	Phase II Components	LTSM Components	Confirmation Report
• draft GCAP	• 25 extraction wells	• additional extraction wells	• continue remediation	• document method of meeting standards
• design	• 15 injection wells	• additional injection wells	• revise LTSP	
• pilot test of treatment system	• infiltration trench	• maximize treatment system capacity	• system O&M	
• procurement	• 100 gpm treatment system	• evap. pond for brine	• system evaluation	
• final GCAP	• evap. pond for brine	• system evaluation	• monitoring	
• duration: 2 years	• system evaluation	• monitoring	• duration: 4 years or until standards are met	
• NEPA documentation done concurrently	• monitoring	• duration: 10 years		
	• duration: 2 years			

1. Time periods and components are estimates and may change due to funding constraints or technical considerations.
2. LTSM components refer only to ground-water remediation activities. LTSM at the site will continue for 200 to 1,000 years.
Key: GCAP=ground-water compliance action plan; LTSM=long-term surveillance & maintenance; LTSP=long-term surveillance plan; O&M = operation and maintenance

Figure 4–5. Conceptual Implementation Plan

Phase I includes installation of approximately 25 extraction wells, 14 injection wells, and the infiltration trench approximately 2,400 ft long located north of the disposal cell. The actual number of extraction wells installed for the first phase will depend on the yield of the wells. The planned extraction rate for Phase I is 100 gpm. Recovery well locations are proposed in the areas with the highest concentrations of contaminants. Injection wells for Phase I are along the downgradient margin of the nitrate plume to control its migration and within the plume to enhance flushing in the areas with the highest concentration of contaminants. The well field for Phase I is planned to operate for two years while monitoring, modeling, and evaluation of the system are done to plan the next phase of well installations.

Phase II is planned to add additional extraction and injection wells to bring the extraction system capacity up to approximately 200 gpm. A final GCAP will be prepared and issued at the time of implementation of Phase II. Monitoring and system evaluation will continue during Phase II. As the system expands, the performance of the well field will be maximized by using phased installation of additional wells, pulsed pumping techniques, and adaptive pumping strategies. Pulsed pumping techniques permit part of the well field to recover periodically, and adaptive pumping strategies are used to induce the movement of ground water from stagnation zones. DOE anticipates that the planned location and number of Phase II wells will change from what is presently anticipated because the actual site conditions encountered during remediation will be different from the conditions estimated with the flow model that was used for the initial
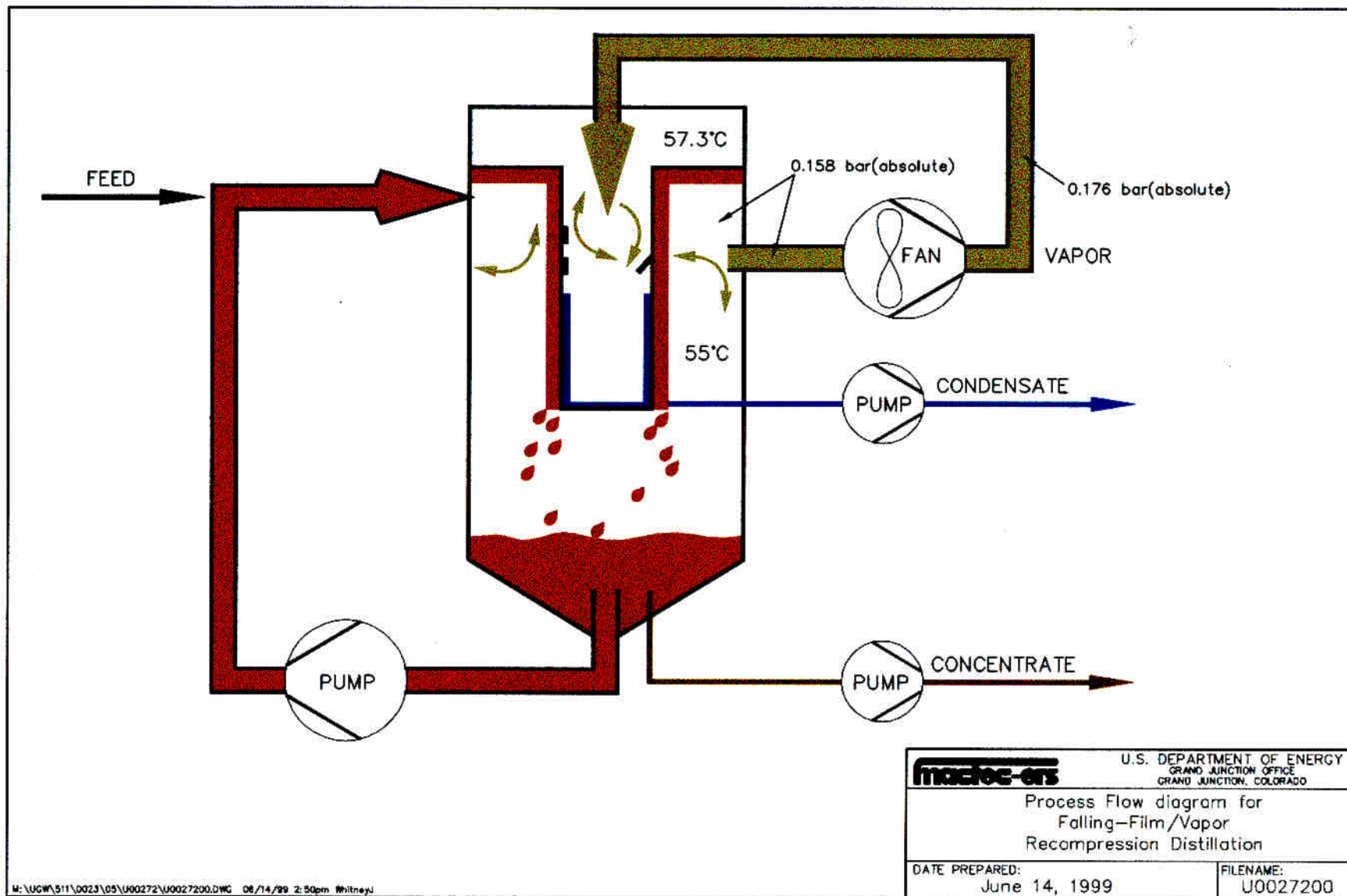
FEED

57.3°C

0.158 bar(absolute)

0.176 bar(absolute)

FAN

VAPOR

55°C

PUMP → CONDENSATE

PUMP

PUMP → CONCENTRATE

mactec-ers

U.S. DEPARTMENT OF ENERGY
GRAND JUNCTION OFFICE
GRAND JUNCTION, COLORADO

Process Flow diagram for
Falling-Film/Vapor
Recompression Distillation

DATE PREPARED:
June 14, 1999

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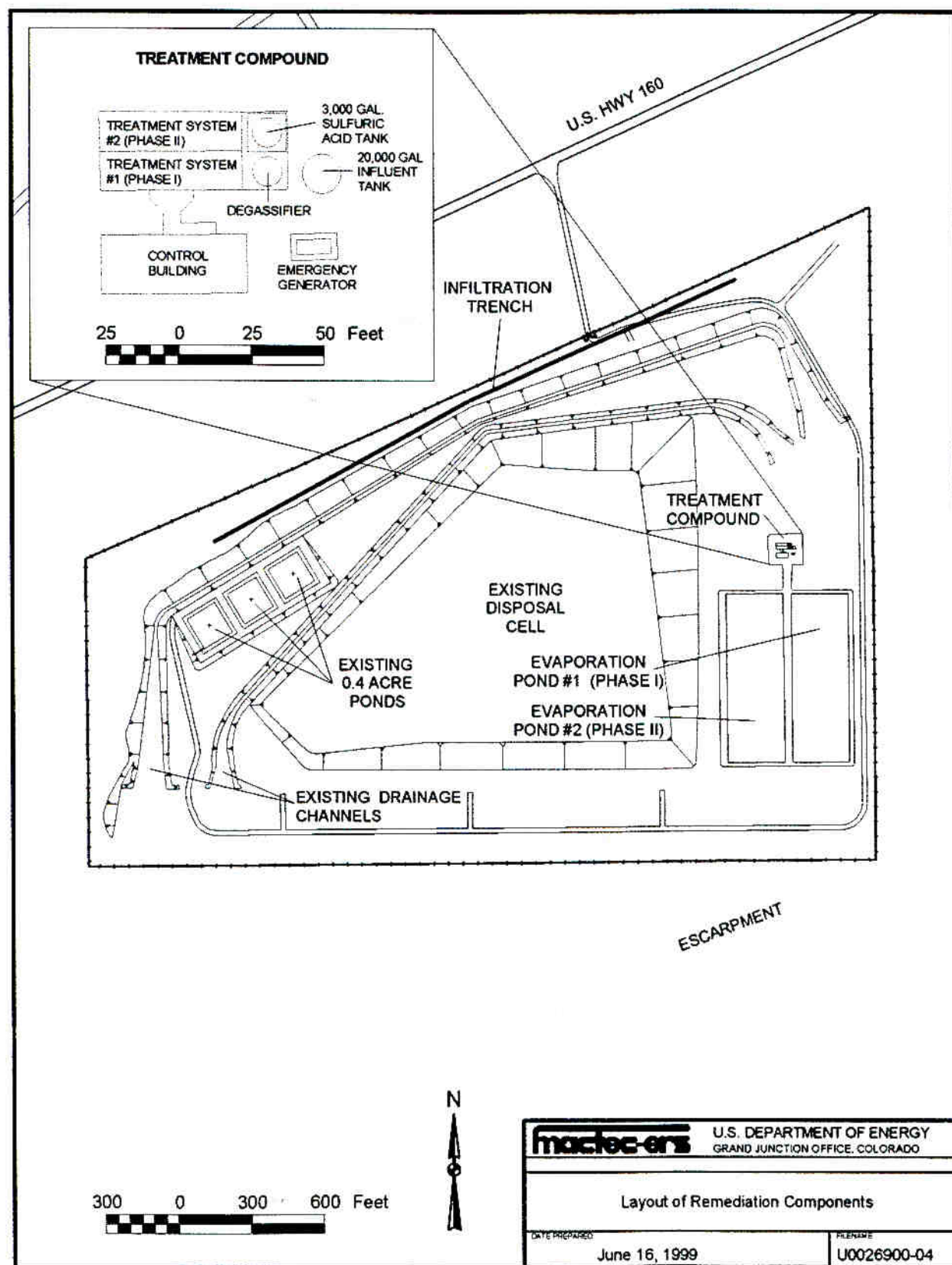*Figure 4-3. Distillation Process Flow Diagram*

Figure 4–4. Layout of Remediation Components

evaluation of the well field. The capacity of the treatment system will be sized to match the extraction rate from the well field, estimated at 200 gpm. Also, the scale-up of the treatment system capacity will match the scale-up of the extraction system. Two treatment units are planned to meet the treatment needs of the extraction system phases. Initially, a treatment unit with a capacity of approximately 100 gpm is planned. At the time of full implementation of the extraction system, a second treatment unit will be installed to give a total treatment capacity of approximately 200 gpm.

Phase II is planned to last approximately 10 years, at which time operation of the system would be transferred to DOE's Long-Term Surveillance and Maintenance Program. The system would continue to operate until cleanup levels were met or the remediation was shown to be no longer effective. A confirmation report will be prepared to document that the standards in 40 CFR 192 were met (i.e., that cleanup standards were met, ACLs were developed, or technical impracticability was implemented).

The existing monitoring program will be used to establish a prepumping baseline. Additional monitoring activities will be done to evaluate the Phase I remediation and plan Phase II activities. Additional monitoring activities include placing data loggers in wells along the perimeter of the site to evaluate prepumping trends and the trends associated with hydraulic head and the concentration of contaminants as pumping continues. Ground-water samples will also be collected from each pumping well as pumping continues. The frequency of the ground-water sampling will be determined during the design. Samples will be analyzed for the contaminants and field parameters that could suggest what geochemical processes are occurring. Monitoring also will be used to evaluate the performance of the extraction and injection system. Monitoring will establish the success of the remediation which will be judged by meeting the cleanup standards and goals in all areas of the aquifer. Monitoring will likely continue for several years after remediation goals and standards have been met. The details of any post-remediation monitoring will be presented in the confirmation report.

Initially, monitoring activities at the site will continue to analyze for all 18 contaminants identified in Section 3.1 that are attributable to milling activities and that have been found at concentrations above background. Although not attributable to milling activities, lead also will be analyzed for since it has been found at concentrations that are close its MCL of 0.05 mg/L. Even though only six of the contaminants (nitrate, molybdenum, selenium, uranium, sulfate, and chloride) have cleanup standards or goals, DOE will monitor for all 19 contaminants as a best management practice. The additional analyses will provide more data on the trend of the concentration of the contaminants and more assurance that their concentrations will not increase in the future. Analysis of the contaminants that do not have a cleanup goal or standard will likely be discontinued after consultation with the concerned parties and after sufficient data are obtained to determine that concentrations are not increasing.

4.4 Limitations of the Selected Remediation Method

Although the selected remediation method (i.e., ground water extraction and treatment, also known as pump and treat) is the best method to meet cleanup goals in the aquifer, the effectiveness of pump-and-treat systems has been limited. Few sites with contaminated ground water have ever been restored to drinking water standards (Travis 1990; EPA 1996), primarily

because of limitations of the extraction systems. Hydraulic inefficiencies, heterogeneity of the aquifer, and sorption of the contaminants to the aquifer material are the main factors that limit the effectiveness of ground water extraction systems.

Hydraulic inefficiencies account for the diffusion of contaminants into low-permeability areas and hydrodynamic isolation (stagnation points) within a well field. Heterogeneities of the aquifer (e.g., changes in the hydraulic conductivity and effective porosity) affect the ability to extract ground water from all areas of the aquifer. The sorption of contaminants to the aquifer material retards the movement of the contaminants in the ground water. The more a contaminant sorbs to the aquifer matrix, the more ground water must be extracted to remove the contaminant.

Hydraulic inefficiencies and heterogeneities of the aquifer are expected to be the main factors that limit the effectiveness of the extraction system at the Tuba City site. Sorption of contaminants is not expected to be significant for nitrate, uranium, and sulfate, but may be significant for selenium and molybdenum.

A common occurrence with almost all pump-and-treat systems is "tailing." Tailing is when there is only a small reduction in the concentration of contaminants in a well over long periods of pumping. It is caused by both sorption of contaminants to the aquifer material and by aquifer heterogenieties. Aquifer heterogenieties (i.e., different permeabilities within the same area) cause tailing because contaminants are removed first from the most permeable areas where there is the highest ground water velocity. After contaminants have been removed from the most permeable areas, the rate of contaminant removal is governed by the slow advection and diffusion of contaminants from the less permeable areas to the more permeable areas. Contaminants in the less permeable areas slowly mix with clean water in the more permeable areas, creating a concentration in the extracted ground water that tends to stay relatively constant with time.

If active remediation cannot achieve the cleanup levels, other methods of protecting human health would be pursued. A provision in 40 CFR 192 allows the use of ACLs that would be set at a higher concentration than the current cleanup goals but that would still be protective of human health. The use of ACLs may require that the area within the fence surrounding the disposal cell be extended to incorporate areas of the plume that could not be remediated to the cleanup levels. Using ACLs and extending the fenced area around the disposal cell would only be considered if active remediation could not effectively reduce contaminant levels in the aquifer to the cleanup standards. Since ACLs will only be considered if active remediation cannot achieve cleanup levels, a more detailed discussion of possible implementation of ACLs, except in the general sense as outlined above, is premature at this stage of the remediation.

5.0 References

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